IS 12366 (1988): Recommended Practice for Heat Treatment of Titanium and Titanium Alloys [MTD 22: Metallography and Heat Treatment]

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(Reaffirmed 2000)

Indian Standard

RECOMMENDED PRACTICE FOR HEAT TREATMENT OF TITANIUM AND TITANIUM ALLOYS

Methallography and Heat Treatment Sectional Committee SMDC 27 [Ref : Doc : SMDC 27 (3222)]

1. Scope — This practice is intended as an aid in establishing a suitable procedure for the heat treatment of titanium alloys to assure proper physical and mechanical properties. Times and temperatures are typical for various forms, sizes and manufacturing methods do not exactly define the optimum heat treatment for a specific item. Therefore, this practice is not intended to be used as a substitute for a detailed production process or procedure.

2. General — Unalloyed titanium undergoes an allotropic transformation from its close packed hexagonal structure (alpha phase) to a body centred cubic structure (beta phase) at 882°C and this structure is stable up to the melting point. Depending upon the effects of elements on this transformation, alloying elements in titanium are classified as being alpha stabilizers, beta stabilizers or neutral. Aluminium and oxygen are alpha stabilizers and raise the alpha to beta transformation temperature. Nitrogen and carbon are also alpha stabilizers, but these elements are usually not added intentionally in alloy formulation. Manganese, vanadium chromium, iron, molybdenum and niobium are beta stabilizers and lower the alpha to beta transformation temperature, and depending upon their content in alloy, retention of some beta phase may result at room temperature. Alloying elements such as tin and zirconium do not significantly affect the alpha-beta transformation temperature, and are soluble in both the phases and therefore, called neutral stabilizer. Based on the type and amount of alloying elements, titanium alloys are classified into 5 classes. These classes are shown in Table 1. Heat treatment of titanium and its alloys can be varied according to the allotropic transformation and other metastable transformation products to generate a large variety of microstructures. Hence, various combinations of mechanical properties can be achieved by suitable heat treatment. When a near alpha or alpha + beta alloy is heated above beta transus, on cooling the beta phase transforms to Widmanstatten alpha plates and grain boundary alpha existing on the prior beta grain boundary. However, amount of grain boundary alpha and size of alpha plates vary a lot with cooling rate. This structure is commonly known as transformed beta structure. A near beta alloy or a beta alloy produces a retained beta structure when cooled from beta region, though some amount of alpha may precipitate out, if cooling is slow. When these alloys are processed in two-phase alpha + beta region and are heated in two-phase region, the structure usually show primary equiaxed alpha and transformed beta or primary alpha, and retained beta depending upon composition of alloy and cooling rate. Some of the typical microstructures for different alloy categories in different heat treatment conditions are shown in Fig. 1.

3. Purpose of Heat Treatment

3.1 Titanium and titanium alloys are heat treated for the following purposes.

a) To reduce residual stresses developed during fabrication (stress relieving);

b) To produce an optimum combinations of ductility, mechineability, and dimensional and structural stability (annealing);

c) To increase strength (solution treating and ageing); and

d) To optimize special properties such as fracture toughness, fatigue strength and high temperature creep strength.

3.2 Not all heat treating cycles are applicable to all titanium alloys because the various alloys are designed for different applications and choice of a heat treatment cycle will depend upon the alloy composition, required properties for its intended application and form in which it is going to be used, that is, sheet, rod, bar, semifinished, finished product or casting.

4. Heat Treatment

4.1 *Stress Relieving*

4.1.1 Generally semi-finished or finished products are subjected to stress-relieving treatments to decrease the undesirable residual stresses that results from: (a) non-uniform deformation from

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cold forming and straightening, (b) assymmetric machining of plates or forgings, (c) welding and cooling of castings, and (d) high temperature solution treatment.

TABLE 1 CLASSIFICATION OF TITANIUM ALLOYS

(*Clause* 2.1)

Alloy Nominal Composition	Commercial Designation	Approximate Stabilizers Addition	Transus Temperature ± 20°C	Microconstituents for Processed Alloys	
				Alpha + Beta treatment	Beta treatment
A) Commercially pure titanium	—	None	—	Equiaxed alpha grains	—
B) Alpha alloys					
Ti-5Al-2·5 Sn	—	None	1050	Equiaxed alpha grains	—
C) Near alpha alloys		/2·0			
Ti-8Al-1Mo-1V			1040	Primary alpha + widmanstaten alpha (primary alpha + transformed beta)	Grain boundary alpha + widmanstaten alpha (transformed beta)
Ti-6Al-2Nb-1Ta-1Mo			1015		
Ti-6Al-5Zr-0·5Mo-0·25Si	Ti 685		1020		
Ti-2·0Al-1·5Mn	OT4-1		920		
D) Alpha-beta alloys		2·0-8·0%		Primary alpha + retained beta	Widmanstaten alpha + grain boundary alpha + retained
Ti-6Al-4V	Ti-6-4 (IMI 318)		1000	Primary alpha + transformed beta (consisting of lamellar alpha and beta)	
Ti-3Al-2·5V	BT-9		935		
Ti-6·5Al-3Mo-1Zr-0·25Si	BT-9		1000		
Ti-4Al-4Mo-2Sn-0·5Si	IMI 550		975		
E) Near beta alloys					
Ti-5Al-2Sn-4Mo-2Zr-4Cr	Ti-17	8·0-10·0%	900	Primary alpha + retained beta	Retained beta + alpha precipitate + grain boundary alpha
F) Beta alloys		Enough to retain beta			
Ti-10V-2Fe-3Al	Ti-10-2·3		805	Primary alpha + retained beta + secondary alpha	Retained beta + secondary alpha
Ti-11·5Mo-6Zr-4·5Sn	Beta III		760		
Ti-3Al-8V-6Cr-4Zr-4Mo	BetaC		795		

4.1.2 When symmetrical shapes are machined in the annealed condition employing moderate cuts and uniform stock removal, stress-relieving may not be required. Separate stress relieving may also be omitted when the manufacturing sequence can be adjusted to employ annealing or hardening as the stress-relieving process.

4.1.3 Temperatures and holding times for stress-relieving treatments for various alloys are given in Table 2. The ranges in both time and temperature indicate that various combinations of temperature and time may yield satisfactory results. The higher temperatures are usually used with shorter times and the lower temperatures with longer times, for effective stress relief. During stress relief of solution treated and aged titanium alloys, care should be taken to prevent overaging to lower strength. This may be accomplished by selecting a time temperature combination that provides partial relief. Uniformity of cooling rather than rate of cooling from the stress relieving tmperature is critical. Oil or water quenching should not be used, because this can induce residual stresses due to non-uniform cooling. In most of the cases furnace or air cooling is acceptable.

4.1.4 Stress relieving treatments must be based on the metallurgical response of the alloy involved. Temperature selected should be high enough to relieve stresses but low enough not to cause any precipitation or strain ageing in alpha-beta and beta alloys and recrystallisation in single phase alloys.

4.1.5 There are no non-destructive testing methods that can be used for measuring the efficiency of stress-relief treatment except direct residual stress measurement by X-ray diffraction. No significant changes in micro-structure can be detected by optical microscopy due to stress relieving heat treatments.

Heat Treatment of α and $\alpha + \beta$ Worked Material

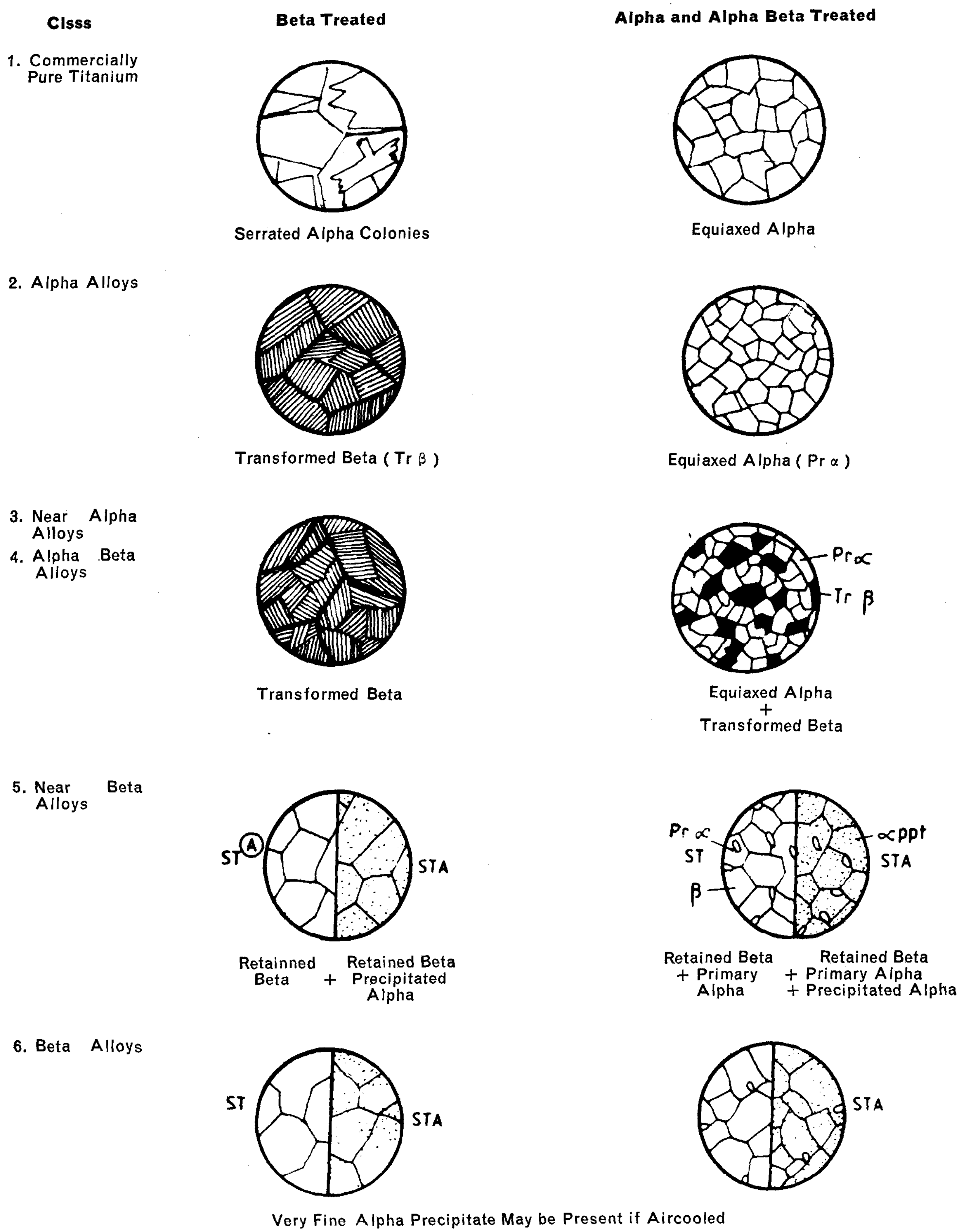


FIG. 1 SCHEMATIC MICROSTRUCTURES OF TITANIUM ALLOYS

TABLE 2 RECOMMENDED STRESS RELIEVING TREATMENTS FOR TITANIUM AND TITANIUM ALLOYS

(*Clause* 4.1.3)

Alloy	Temperature °C	Time, h	Cooling Method
A) Commercially pure titanium (all grades)	475-600	1/4 to 4	FC/AC
B) Alpha alloys Ti-5Al-2·5Sn	525-650	1/4 to 4	FC/AC
C) Near alpha alloys			
Ti-8Al-1Mo-1V	590-700	1/4 to 4	FC/AC
Ti-6Al-2Nb-1Ta-1Mo	590-650	1/4 to 2	FC/AC
Ti-6Al-2Sn-4Zr-2Mo	600-700	1/4 to 4	
Ti-6Al-5Zr-0·5Mo-0·25Si	550-650	2 to 8	FC/AC
Ti-2Al-1·5Mn	520-560	1/4 to 4	FC/AC
D) Alpha-beta alloys Ti-6Al-4V	475-650	1/4 to 4	FC/AC
Ti-3Al-2·5V	525-650	1/4 to 2	FC/AC
Ti-6·5Al-3Mo-1·5Zr-0·25Si	530-580	1 to 6	FC/AC
E) Near beta alloys			
Ti-5Al-2Sn-4Mo-2Zr-4Cr (Ti-17)	475-650	1 to 4	FC/AC
F) Beta alloys			
Ti-10V-2Fe-3Al	675-700	1/2 to 2	FC/AC
Ti-11·5 Mo-6Zr-4·5Sn	720-730	1/12 fo 1/4	FC/AC
Ti-3Al-5V-6Cr-4Zr-4Mo	700-750	1/6 to 1/2	FC/AC

4.2 *Annealing*

4.2.1 Annealing of titanium alloys is used to achieve the suitable microstructure and/or the required combination of mechanical properties. Since improvement in one or more properties is generally obtained at the expense of some other property, annealing cycle should be selected according to the properties required. Common annealing treatments are:

a) *Mill annealing* — It is a general purpose treatment given to all mill products. It is not full anneal and may leave traces of working in the microstructure of heavily worked products, sheets, etc.

b) *Duplex annealing* — It is normally done below β transus and changes shapes, sizes and distribution of phases to those required for improved creep resistance or fracture.

c) *Triplex annealing* — It is also done below β transus and is done to meet the same objectives as duplex annealing.

d) *Recrystallization* — It is normally done to recrystallize the worked structure to refine grain size.

e) *Beta Annealing* — This treatment is done at temperature above the beta transus of the alloy and is generally used to improve fracture toughness and strength and creep resistance while lowering its ductility.

4.2.2 Recommended annealing treatments for various alloys are given in Table 3. Since microstructure of most of the alloys and hence mechanical properties are sensitive to cooling rate, cooling practice should be decided keeping the objective of the heat treatment in view.

4.2.3 Straightening, sizing and flattening may be combined with annealing by use of appropriate fixtures. The parts in bulk or in fixtures, may be charged directly into a furnace operating at the annealing temperature. Distortion of thin sections should be prevented by proper fixtures. Special flattening techniques like creep flattening and vacuum creep flattening may be used to get flat sheets and plates.

4.3 *Solution Treating and Ageing*

4.3.1 This treatment is applied to near β and β alloys to obtain a wide range of strength levels. Heating an alpha-beta or beta alloy to solution treating temperature and then quenching helps to

retain supersaturated beta phase at room temperature. On subsequent ageing, metastable beta phase decomposes to give fine alpha precipitates, providing high strength. Commercial beta alloys generally supplied in the solution treated condition, need only be aged.

TABLE 3 RECOMMENDED ANNEALING TREATMENTS FOR TITANIUM AND TITANIUM ALLOYS

(*Clause* **4.2.2**)

Alloy	Temperature °C	Time, h	Cooling Method
A) Commercially pure titanium (All grades)	650-760	1/10 to 0	Air cooling
B) Alpha alloys			
Ti-5Al-2·5Sn	725-850	$\frac{1}{6}$ to 4	AC
C) Near Alpha alloys			
Ti-8Al-1Mo-1V	790 (a)	1 to 8	AC/FC
Ti 6Al-2Nb-1Ta-1Mo	790-900	1 to 4	AC
Ti-6Al-2Sn-4Zr-2Mo	900	$\frac{1}{2}$ to 2	AC
Ti-6Al-5Zr-0·5Mo-0·25Si	740-790	1 to 4	AC/FC
Ti-2Al-1·5Mn	640-690*	$\frac{1}{6}$ to 1	FC
D) Alpha-beta alloys			
Ti-6Al-4V	700-790	1 to 4	AC/FC
Ti-3Al-2·5V	650-760	$\frac{1}{2}$ to 2	AC
Ti-6·5Al-3Mo-1·5Zr-0·25Si	950-980	$\frac{1}{2}$ to 2	AC
Ti-4Al-4Mo-2Sn-0·5Si	900	$\frac{1}{2}$ to 4	AC
E) Near Beta alloys			
Ti-5Al-2Sn-4Mo-2Zr-4Cr	†	‡	
F) Beta alloys			
Ti-10V-2Fe-3Al	†	†	
Ti-11·5Mo-6Zr-4·5Sn	690-760	$\frac{1}{6}$ to 1	AC/WQ
Ti-3Al-8V-6Cr-4Zr-4Mo	790-815	$\frac{1}{4}$ to 1	AC/WQ

*For sheet and plate follow by $\frac{1}{4}$ h at 790°C then aircool.

†Not normally supplied or used in annealed condition.

‡For cold-rolled sheets.

4.3.2 Selection of solution treatment temperature usually is based upon the desired level of tensile properties and the amount of ductility to be obtained. Generally alpha + beta alloys are solution treated at a temperature high in the alpha beta field. Since the solution treatment is done at temperature slightly below β transus, a precise temperature control is essential. Beta alloys are normally obtained from producers in the solution treated condition. If reheating is required, soak-time should be kept minimum to obtain complete solutionizing, since rapid grain growth is observed in the absence of any second phase. Table 4 presents solution treating and ageing treatments for titanium alloys.

4.3.3 The rate of cooling from solution treating temperature should be high enough to prevent decomposition of beta phase during cooling. The cooling practice required for complete retention of high temperature beta phase will depend upon the composition of the alloy and section size. Air or fan cooling may be adequate for alloys high in stabilizing elements and for products of small section size. Beta titanium alloys generally are air cooled from the solution treatment temperature.

Water or a 5 percent brine or caustic soda solution is required for quenching alpha-beta alloys to retain high temperature beta phase without decomposition. The need for rapid quenching is further emphasized by short quenching delay time requirements. Depending upon the mass of the sections being heat treated, some alpha-beta alloys can only tolerate a maximum delay of 7 seconds while beta alloys can tolerate quench delay time up to 20 seconds.

Section size influence effectiveness of quenching and, in turn, response to ageing. The amount and type of beta stabilizers in the alloy determine the depth of hardening or strengthening.

4.3.4 Ageing causes decomposition of supersaturated beta phase retained on quenching. A summary of ageing time and temperature is given in Table 4. The time/temperature combination is

selected depends on required strength. Ageing at or near annealing temperature results in overageing, called solution treated and overaged (STOA), is sometimes used to obtain modest increase in strength while retaining toughness and dimensional stability. Although the aged condition is not necessarily one of equilibrium, proper ageing produces high strength with adequate ductility and metallurgical stability.

TABLE 4 RECOMMENDED SOLUTION TREATING AND AGEING (STABILISING) TREATMENTS FOR TITANIUM ALLOYS

(*Clause* 4.3.4)

Alloy	Solution Temperature °C	Solution Time, h	Cooling Rate	Ageing Temperature °C	Ageing Time, h
A) Near alpha allloys					
Ti-8Al-1Mo-1V	980-1010*	1	OQ/WQ	565-505	
Ti-6Al-2Sn-4Zr-2Mo	960-980	1	OQ/WQ	600	8
Ti-6Al-5Zr-0·5Mo-0·25Si	1065	½ to 1	OQ/AC	530-580	12-36
B) Alpha-beta alloys					
Ti-6Al-4V	955-970†	1	WQ	475-600	4 to 8
Ti-3Al-2·5V					
Ti-6·5Al-3Mo-1·5Zr-0·5Si	950-980	½ to 2	AC	530-580	4 to 2
Ti-4Al-4Mo-2Sn-0·5Si	850-920	½ to 2	AC	480-520	12 to 36
C) Near beta alloys					
Ti-5Al-2Sn-4Mo-2Zr-4Cr	845-870	1	AC	575-600	4 to 8
D) Beta alloys					
Ti-10V-2Fe-3Al	760-780	1	WQ	405-525	8
Ti-11·5Mo-6Zr-4·5Sn	690-793	⅛ to 1	AQ/WQ	475-600	8 to 32
Ti-3Al-8V-6Cr-4Cr-4Mo	815-929	1	WQ	450-550	8 to 24

**For certain products, use solution temperature of 890°C for 1 h, then air cool or faster.*

†For thin plates or sheets, solution temperature can be used down to 890°C for 6 to 30 min, then water quench.

‡*This treatment is used to get maximum tensile property in this alloy.*

During ageing of some highly beta stabilized alpha-beta alloy or beta alloys, beta transforms first to metastable transition phase referred to as omega phase which produces brittleness. This can be avoided by severe quenching and rapid reheating to ageing temperatures above 425°C. Ageing temperatures selected are such that omega phase transforms to alpha at those temperatures.

4.4 *Other Special Heat Treatments*

4.4.1 Certain physical properties such as notch strength, fracture toughness and fatigue resistance can be enhanced by special thermal treatments. Some of these heat treatments are given in Table 5.

TABLE 5 RECOMMENDED SPECIAL THERMAL TREATMENTS FOR CERTAIN ALLOYS

Alloy	Heat Treatment	Advantages
Ti-6Al-4V	Solution treating and over-ageing heat 1 h at 955°C, water quench; then 2 h at 705°C, air cool	Improved notch strength fracture toughness and creep strength at strength level similar to those obtained by regular annealing
Ti-6Al-4V	Recrystallization annealing: heat 4 h or more at 925-955°C, furnace cool to 760°C at a rate less than 50°C/h, cool to 475°C at a rate higher than 370°C, air cool to room temperature	Improved fracture toughness and fatigue crack growth characteristics at somewhat reduced level of strength
Ti-6Al-4V	Beta annealing; Heat 5 min to 1 h at 1010-1040°C, air cool to 650°C at a rate of 85°C/min or higher, then 2 h at 730-790°C	Improved fracture toughness high cycle fatigue strength and resistances to acquire stress corrosion
Ti-6Al-2Sn-4Zr-2Mo	Beta annealing, heat ½ h at 1020°C, air cool, then 8 h at 595°C, air cool	Improved creep strength at elevated temperature as well as improved fracture toughness

4.5 Heating Time — The heating time of semi-finished and finished parts up to the given temperature of annealing or solutionizing is recommended to be established depending upon the thickness or diameter of heating material in the limits indicated in Table 6. In every specific case, the heating time is established depending upon the furnace ratings, quantity of charge, and section of semi-finished and finished parts. This heating time should be added to the heat treatment time given in Tables 2-5.

TABLE 6 RECOMMENDED HEATING TIME DEPENDING UPON THE THICKNESS/DIAMETER

Diameter or Thickness, mm	Heating Time, minutes	
	Minimum	Maximum
Up to 3	5	10
10-20	10	20
Above 20 up to 30	15	30
Above 30 up to 50	20	40
Above 50 up to 70	25	50
Above 70 up to 100	30	60
Above 100 up to 130	40	70
Above 130 up to 160	50	80
Above 160 up to 200	60	90
Above 200 up to 230	80	110

Note — Heating time for flat billets of disc type should be increased by 1·5 times as compared to the specifications in table. For welded constructions, it is established experimentally.

Heating time for billets with thickness of more than 250 mm is not specified and is to be established.

5. Post-Heat Treating Requirements

5.1 Titanium reacts with oxygen, water and carbon dioxide normally found in oxidizing heat treating atmospheres and with hydrogen formed by decomposition of water vapour. Unless the heat treatment is performed in vacuum or in an inert atmosphere, oxygen will produce an oxygen enriched layer commonly known as 'alpha case' on the metal surface. An example of alpha case in microstructure of an $\alpha + \beta$ alloy is shown in Fig. 2. This brittle layer must be removed before the component is put in the service. It is advisable to remove this layer in semi-finished products also to prevent oxygen diffusion deeper in the metal. It can be removed by machining or by other mechanical methods or by chemical methods (pickling) or by both.

5.2 Oxidation rates of commercial titanium alloys vary and Table 7 can be used as a guide to determine as to how much material should be removed. Temperature and total time of holding at temperature must be known. One method to check for complete removal of alpha case is to etch the product with a solution composed of 18 g of ammonium bifluoride per litre of water. Light grey indicates presence of alpha case, dark grey indicates its absence. For mill products such as plates, micro examination of representative samples removed from the plate can be used.

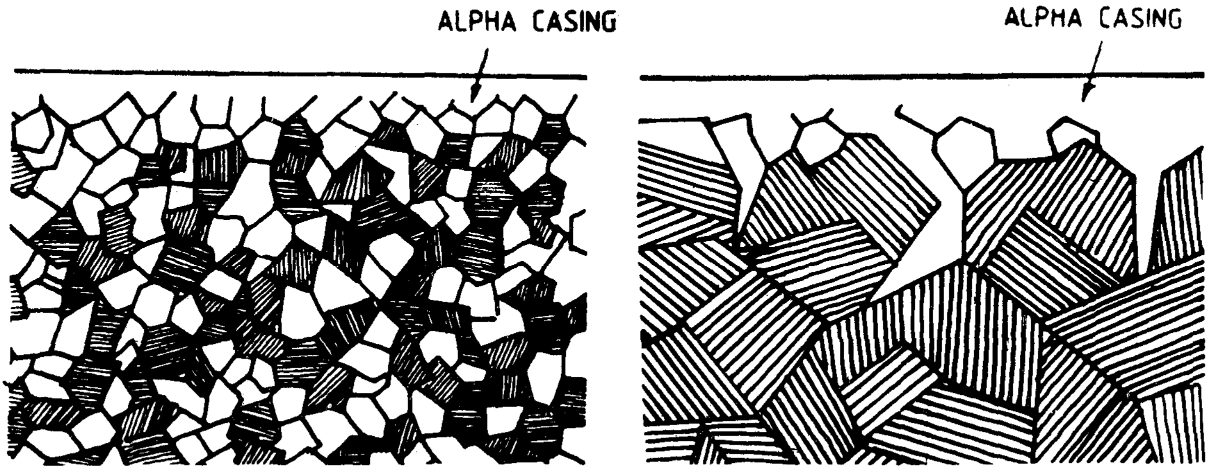
5.3 Small amount of hydrogen (100 to 200 ppm) can be tolerated in titanium alloys with the specific limiting amount determined by the type of alloy. High hydrogen content can lead to premature failure of a component. Hydrogen pick up occurs not only during heat treatment but also during pickling. The amount of hydrogen pick up can only be determined by vacuum fusion method of analysis. If high hydrogen content is found, vacuum annealing is required.

5.4 Efficiency of heat treatment should be checked by appropriate mechanical tests for the properties to be verified. Hardness is not recommended as a non-destructive method of checking because the correlation between strength and hardness is poor. The test pieces can be cut from parts or technological allowances on parts. For parts stamped from sheet billets, it is permitted to check on specimen blank samples, having passed all the cycles of heat treatment for the alloy. Typical values of the mechanical properties of various alloys are given in Table 8 and can be used as a guide for comparison of test results.

6. Furnace Equipments and Accessories

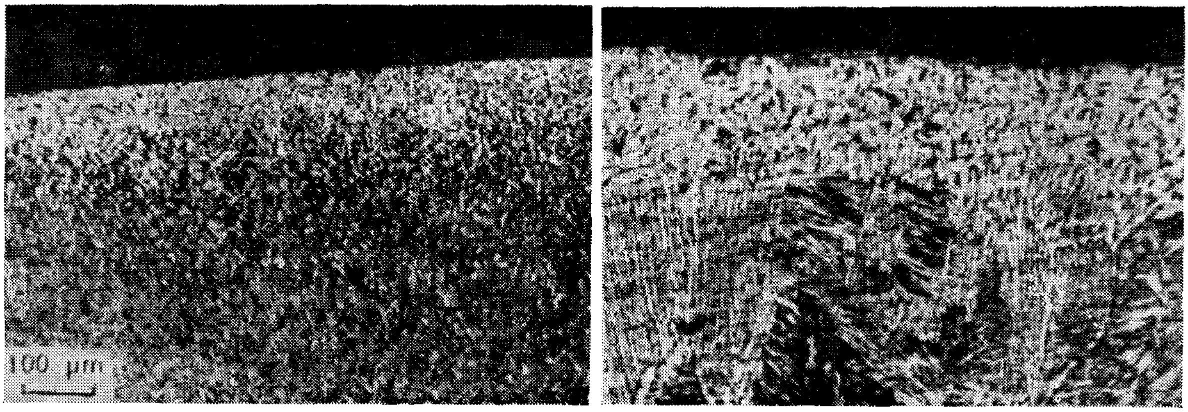
6.1 *Furnace* — Titanium alloys should be heat treated only in electrical furnaces with automatic regulation and recording of temperature. The temperature controller equipment should be capable of controlling and rocording the desired temperature within ± 10°C. It is not recommended to heat the titanium alloys during heat treatment in nitrate baths or gas or oil fired furnances. For preventing formation of scales, finished parts and sheet should be heat treated in vacuum furnaces or

in furnaces with inert atmosphere. An antioxident oxidation resistant spray coating may be applied on parts in order to minimize oxygen pick up while heat treating in air furnaces. Such coating work effectively at temperatures up to about 760°C, but their use does not fully eliminate the need for removing the surface structure after heat treating. At normal ageing temperature of 480-590°C, heat treatment can be carried out in air.



(a) (b)

Alpha shown schematically for (a) alpha + beta and
(b) beta heat treated conditions



(c) (d)

Alpha casing in BT-9 alloy for (c) alpha + beta and
(b) beta heat treated conditions

FIG. 2 ALPHA CASING IN DIFFERENT HEAT TREATED CONDITIONS

6.2 *Quenching Media* — Water or 5 percent brine or caustic soda solution is most widely used as the quenching medium. Low visocosity oil with a high flash point may be used in vertical immersion quenching of sheets to reduce distortion. However, choice of quenching media should be made depending upon the cooling rate required, temperature of the treatment and section size.

6.3 *Fixtures* — In selecting fixtures for preventing distortion during test treatment, the thermal expansion characteristics of both the titanium alloy and the fixture itself must be considered. Ideally both the alloy and fixture should have equivalent thermal expansion characteristics within the intended temperature range. Mild steel is commonly used at low temperature ageing treatments. However, allowance must be made for the slight differences between the thermal expansion of mild steel and that of titanium to avoid undesirable distortion.

6.4 Periodical checking and calibration of the furnaces should be done (at least once in six months). After changing the heaters and other repairs of the furnace, the furnace should be subjected to comprehensive inspection and temperature calibration should be done for different points of the working chamber. On the basis of this calibration, the working zone where the parts may be loaded for heating should be established.

TABLE 7 RECOMMENDED MINIMUM METAL REMOVED AFTER THERMAL EXPOSURE OF TITANIUM ALLOY

(*Clause* 5.2)

Heat Treating Temperature °C	Time at Temperature h	Minimum Stock Removed per Surface* mm
480-600	Up to 12	0·005
601-650	Up to 4	0·010
	4 to 12	0·015
651-700	Up to 1	0·015
	1 to 8	0·020
	8 to 12	0·025
701-750	Up to 1	0·025
	1 to 4	0·035
	4 to 8	0·040
	8 to 12	0·045
751-800	Up to ½	0·035
	½ to 1	0·040
	1 to 2	0·050
	2 to 4	0·060
801-900	Up to ½	0·060
	½ to 1	0·090
	1 to 2	0·080
851-900	Up to ½	0·060
	½ to 1	0·080
	1 to 2	0·090
901-925	Up to ½	0·080
	½ to 1	0·090
	1 to 2	0·110
926-950	Up to ½	0·010
	½ to 1	0·110
	1 to 2	0·120

*Values shown are typical, actual values may vary with alloy type.

7. Precautions

7.1 A sufficient allowance for post treatment metal removal should be provided.

7.2 Components, fixtures and furnace should be cleaned prior to heat treatment. Ordinary tap water should not be used in cleaning of titanium components.

7.3 Temperature controls with an upper cut-off should be used to prevent temperature from exceeding beta transus.

7.4 Components should be stacked and supported in such a way so as to allow free access of heating and quenching media.

7.5 Alpha case should be removed after completion of all the heat treatments. However, where low oxygen content is desirable, alpha case should be removed after each heat treatment. Do not rely on inert atmosphere or vacuum for prevention of oxygen contamination.

7.6 Assemblies with faying surface should not be pickled.

TABLE 8 TYPICAL VALUES OF THE MECHANICAL PROPERTIES OF TITANIUM AND ITS ALLOYS

(*Clause* 5.4)

Alloy	Condition	Mechanical Properties		
		Y. S. kg/mm²	U. T. S. kg/mm² *	Percent Elongation
a) Commercially pure titanium*		18-28	25-35	20-25
b) Alpha alloys Ti-5Al-2·5Sn	Annealed	80·5	84·0	10
c) Near alpha alloys Ti-8Al-1Mo-IV	Stabilized Annealed	84·0	91·0	10
Ti-6Al-2Nb-1Ta-1Mo	Annealed	76	86·0	14
Ti-6Al-5Zr-0·5Mo-0·25Si	STA	85	100	6
Ti-2Al-1·5Mn	Annealed	55-65	60-75	20
d) Alpha-beta alloys				
Ti-6Al-4V	Annealed	84·0	91·0	10
Ti-3Al-2·5V	Annealed	62·0	65·0	22
Ti-6·5Al-3Mo-15Zr-0·25Si	STA	95-115	105-125	10-14
Ti-4Al-4Mo-2Sn-0·5Si	STA	100	114	9
e) Near beta alloys Ti-5Al-2Sn-4Mo-2Zr-4Cr	STA	108-115	115-122	8-15
f) Beta alloys				
Ti-10V-2Fe-3Al	Annealed	92	96	18
	STA	120	135	8
Ti-11·5Mo-6Zr-4·5Sn	ST	62	69	12
	STA	117	124	6
Ti-3Al-8V-5Cr-4Zr-4Mo	ST	83	86	8
	STA	117	124	12

*Depends on oxygen content.

EXPLANATORY NOTE

Titanium and its alloys possess high specific strength and excellent corrosion resistance and are being increasingly used in many chemical, aerospace and other industrial applications.

Mechanical properties of titanium and its alloys can be modified by suitable heat treatment to meet the specific applications.

This standard has been prepared as a guide for the manufacturers and the users of titanium and its alloys in finished or semifinished product for selection of an optimum heat treatment to get the required mechanical properties for the specific application.

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